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Multi-layer Energy Savings in Optical Core Networks

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***Abstract*—We propose a multi-layer energy saving technique for optical core networks that aims at reducing energy consumption by powering off components in different layers of the network. After obtaining satisfactory results in saving energy by powering off ports in the IP layer in our previous work, in this paper we target more savings by considering additional layers in the network. The model proposed in this paper is a heuristic that bases the capacity prediction for a future time slot on the number of 40G links needed in the current time slot. It also revolves around four parameters for which the values are empirically set. We set two thresholds, low and high, as well as the number of links to power off or power on each time the utilization is below or above a threshold. We assess our model through experiments featuring an Internet2-like topology and a real one-day worth of traffic split into five-minute time slots. The results offer a comparison between different parameters settings and how they affect energy savings and the number of overflows in the network that result from mis-prediction. That said, we demonstrate that our model can achieve up to 90% reduction in energy consumption in the best case when the future traffic is known; otherwise, the savings can range between 82% and 88%, with the occurrence of a small amount of traffic overflow events.**

Keywords*—*Optical Network; energy saving; multilayer; Internet2

I. INTRODUCTION

Introducing energy-efficient design in network has been researched for years. Most green network researchers apply methods on a single network facet or one single layer. However, a practical network is normally composed of multiple layers. Energy-saving operations attempted on upper layers not only might change the upper layer structure but also might influence the lower layer routing and structure. Thus, it is more meaningful to examine energy efficiency based on multi-layer network scenarios. Optical networks are composed of three major layers: IP layer, WDM layer and fiber layer. The IP layer usually has ports operating at 40G (OC768) and 10G (OC192), which are the major energy consumption sources. The WDM layer consumes energy for optical transponders, regenerators and OXCs. The fiber layer consumes energy for amplifiers and some underlying elements. Shutting off ports at the IP layer will shrink some composite links' capacity and might influence the WDM layer topology. With the above consideration, the energy-saving computation becomes complicated. Previously, we designed a dynamic traffic-driven energy-saving model for the IP layer [6]. In this paper, we extend the model to cover the WDM layer along with the fiber layer. In what follows, we list the related work before we provide details on our proposed method. Then we describe the experiment topology, traffic and software. Finally, we outline the results obtained using different modes of our proposed method and conclude this paper.

II. RELATED WORK

Numerous researchers have studied the design and operation of green networks making energy efficiency in optical networks their main concern. Due to space limitations, we only list a few of them here. Y. Zhang et al. [1] provide a detailed survey of energy efficiency in telecom optical networks. A. Bianco et al. [2] introduced energy efficient design in WDM layers. They use a Genetic Algorithm (GA) based meta-heuristic and considered power consumption minimization as optimization target based on traditional LTD+RWA optimization target. Four energy aware IP-over-DWDM models are discussed in [3] where the authors also built up four different energy consumption models comparing their power saving performance on two different network topologies. They have shown that their model can achieve good results though they used a static topology and traffic matrix. The authors in [4] provide good references for power consumption values of modules in a multi-layer optical network. Their paper provided a simplified power consumption model that eases the power consumption computation for large networks. In [5], the authors run a MILP engine on static daily-varying traffic and power on/off IP and WDM layers' elements to minimize power consumption. In the next section, we present our model that we built based on our previous experience and on the different models in these references.

III. POWER SAVING METHODS

The model is composed of three layers: IP layer, WDM layer and fiber layer. The IP layer is based on our previous model [6]. The major energy consumption elements in IP layer are line cards and ports in IP routers, which are for O/E/O (optical-electrical-optical) conversions and IP traffic transport. Each site has two core IP routers and composite links connect them. A pair of ports constitutes a sublink and several sublinks constitute a composite link. In the model, we assume each composite link is mainly composed of 40G ports and one special line card which has four 10G ports. That special line card is always powered on to guarantee that we maintain a stable IP layer topology. Each router monitors its composite link's utilization (whether it changes up or down) to power on or off its router ports in the next timeslot. Four major parameters are set in the heuristic: the high-threshold, the low-threshold, power-on ports and power-off ports. When the link utilization is higher than high-threshold, we power on sublinks by the number of power-on ports; when the link utilization is lower than low-threshold, we power off sublinks by the number of power-off ports. The number of ports to power on/off depends on our choice of the strategy, Conservative or Aggressive. When the traffic gets very bursty, the model might predict wrongly leading to traffic overflow and an alert will be triggered to increase the number of active sub links. The WDM layer is composed of regenerators, transponders and OXCs (optical cross connects) and it routes traffic across the WDM links. When the upper IP layer changes the capacities of composite links, the WDM layer might adjust its routing of WDM traffic to different WDM links and change the regenerators' power status (on or off) by the methods in [7] to achieve energy savings. The fiber layer is composed of amplifiers and some underlying elements. Because many wavelengths in the fiber might share the same amplifier and the activation process of amplifier is kind of slow, we prefer to always power on the amplifiers. However, we might save energy by routing traffic to different fiber spans corresponding to the changing of the WDM links. We set empirical energy consumption value for the above devices as follows: energy consumption of IP router port is 14.5 watts/G; energy consumption of regenerator is 50 watts/10G; energy consumption of OXC is 1.5 watts/10G; and power consumption of underlying common elements are 1 watt/mile.

We propose and compare three different modes in terms of the energy savings and possible overflows.

A. Oracle Mode

In the first part of the experiment, we compute the maximum energy saving possible by setting an Oracle mode. That is to say, when running the experiment, we assume full and complete knowledge of the traffic amount to be requested, hence only the needed number of links is switched on. This results in a theoretical maximum energy savings which is unachievable in practice and is used only as a benchmark.

B. Conservative Mode

The Conservative mode is aimed at getting the minimum number of traffic overflows possible at the expense of a reduction in the energy savings. The parameter setting which allowed us to achieve a low percentage of overflows while still obtaining a relatively high energy saving consists of the following values 55%, 1%, 2 and 1 respectively for the high threshold, low threshold, the number of links to power on and the number of links to power off.

C. Aggressive Mode

The Aggressive mode's parameter setting was such that the experiment yields an energy saving as close as possible to the maximum energy saving by the Oracle mode. We set the high threshold to 70% and the low threshold to 5% and each time we either power on or off one link at a time.

In addition, we also compute the Maximum Energy Consumed in the network for each timeslot for comparison purposes. This is computed for an overprovisioned network operating without turning off any components on any link.

IV. Experiment

A. Topology and Traffic

To assess the performance of the proposed method, it was tested on the traffic of an Internet2-like network over one month. The network topology includes three layers with 400 Gbps capacity on each link. In the IP layer, it has 9 sites, 18 IP routers and 26 composite links. In the WDM layer, it has 43 ROADMs connected through 104 links. And in the fiber layer, it has 327 optical amplifiers constituting 674 spans which is the equivalent of 32,802 miles. We assume the majority of composite links are 40G links to simulate a large ISP network. Also we utilize one day (July 1st, 2010) of original Internet2 traffic data which has 288 files (sampled every five minutes) traffic trace files in the form of RRD (Round Robin Database). We scale it up by forty times to simulate a large core network traffic as our IP layer traffic input.

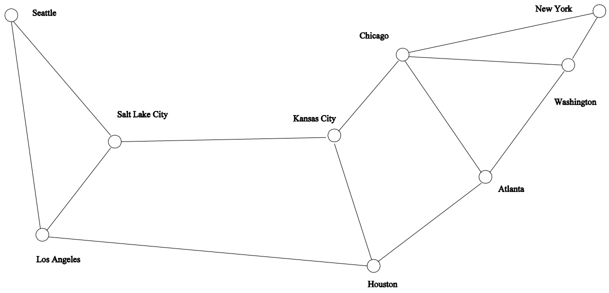

Fig. 1. Internet2-like topology. All links are bidirectional and have 400 Gbps capacity.

For the simulation, the traffic files are reformatted to specify the number of 40G and 10G links. Then we apply our energy consumption model to calculate energy consumption of devices in three layers, possible energy savings and the occurrences of overflow. The next section explains in more details how the traffic files were used.

B. Experiment Software

The experiment was done in two stages. The first stage consisted of preprocessing the data in the traffic files. The traffic amount in the two lines corresponding to the same link were summed up and split into the corresponding number of 40G and 10G links. That is to say, each file contains 26 lines of data each one specifying the number of 40G and 10G needed to carry the traffic of the link. The 288 files are then fed to a multi-layer routing software. In this second stage, the software finds the shortest path for routing traffic for each pair of cities. The routing is done on the three layers of the network: the fiber layer, WDM layer and the IP layer, and energy spent in each of them is computed. This piece of software considers the energy consumed both within the network and in the facilities used to maintain the functioning of the network. The experiment is run multiple times testing the algorithm in different combinations of the four parameters. The results of each of the combinations are discussed in the next section.

V. Results

A. Maximum Energy Saving – Oracle Mode

By running this experiment on the traffic data described earlier, the average energy saving was 90.60% as the graph in figure 2 shows.

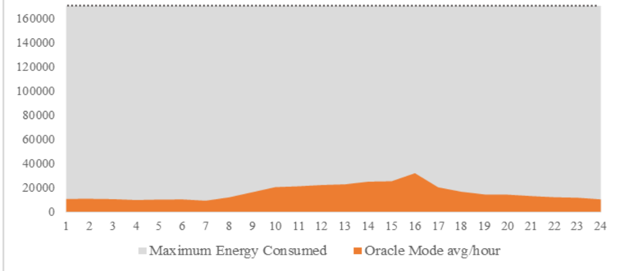

Fig. 2 Average energy consumption per hour under Oracle mode.

B. *Energy Saving Model Results*

1) *Conservative Mode*

Figure 3 shows the energy saving obtained after running the experiment in the Conservative mode described earlier.

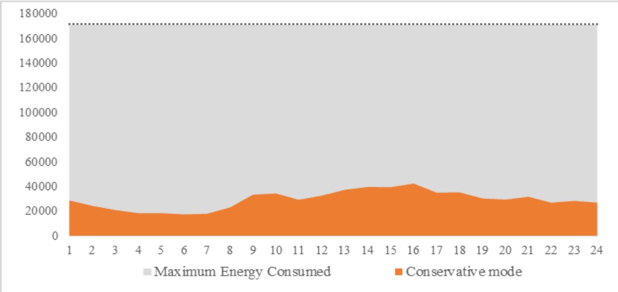

Fig. 3 Average energy consumption per hour under Conservative mode.

The energy saving dropped to 82.82%; likewise, the percentage of overflows in the network dropped to 3.70%. The energy saving that resulted from this experiment is still very closer to the maximum energy that can be saved.

2) *Aggressive Mode*

Figure 4 depicts the results of the experiment running in the Aggressive mode.

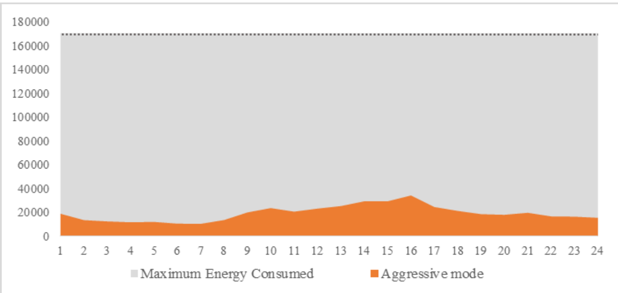

Fig. 4 Average energy consumption per hour under Aggressive mode.

The graph shows that when compared to the Oracle energy saving, our method with the parameters specified earlier resulted in a very high energy saving that reached an average of 88.66%. The prediction algorithm results in fairly good energy saving; however, to realize this much saving the network experienced an average of 9.76% of overflows in the 7488 links used in the whole network in this one-day period.

3) *Three Modes Comparison*

The graph in figure 4 depicts the difference in the average energy consumption under the three modes of operation. When operating the method on the Conservative mode, the energy consumption reach the highest values across the whole day. This keeps a very low number of traffic overflows as the experiment results proved. The Aggressive mode results in energy saving results very close to the Oracle mode's performance. In order to reach energy savings that are this high, the network managers should be able to tolerate a relatively high number of traffic overflows which might attain up to 10%. The bottom line in the graph shows the minimum energy that can be spent with a full knowledge of the traffic needs.

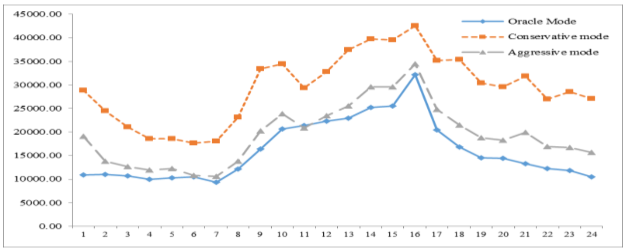

Fig. 5 The three modes average energy consumption per hour comparison.

VI. Conclusion

We have proposed in this paper a multi-layer energy saving method that operates under three different modes. This method is applied to multiple layers of the optical network instead of a single layer which leads to more savings in energy consumption. We proved that energy can be saved by switching ports and other components in both the IP layer and the WDM layer. We defined four parameters: high-threshold, low-threshold, power-on number and power-off number that allow to dynamically power off and on a number of ports depending on the utilization of the network. The three modes of the method are Oracle, Conservative and Aggressive. The Oracle mode assume complete knowledge of the traffic which leads to the best case scenario that cannot be applied in real life but is used for references. The other two modes proposed are the Conservative and the Aggressive, and that are obtained by changing combination of the method parameters. On the one hand, the Conservative performs well for traffic overflow sensitive networks, since it results in less energy savings for less traffic overflows. The Aggressive mode, on the other hand, leads to mode energy savings with a little bit higher number of traffic overflows. We tested those three modes on an Internet2-like network using traffic data that was generated after a month of monitoring of Internet2 network in 2010. This work can be enhanced by testing the three models on other network topologies and different scenarios and may be extended by considering OTN in addition to WDM and IP layers. Finally, when proved to be operational for different experimental topology, we would test it on a real practical network.

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